Comparisons of Damage-Risk Criteria (DRC) for Impulsive Noise: Evidence from firearm blast signals

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Background

- Impulse noise exposure is a known risk factor for hearing impairment.
  - Military and Civilian populations
- There is no single agreed-upon method for estimating risk.
  - Damage-Risk Criteria (DRC)
- More than 50 years of history with some DRC that are now discarded.
- Perhaps the results obtained with other DRC can be transformed into new DRC values.
  - Conserves resources

Damage-Risk Criteria

<table>
<thead>
<tr>
<th>Method</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>HEL 5-1-43B (1965)</td>
<td>Peak, envelope duration, pressure-wave duration</td>
</tr>
<tr>
<td>CHABA (1968)</td>
<td>Peak, envelope duration, Middle ear muscle contractions</td>
</tr>
<tr>
<td>Pflander (1975)</td>
<td>Peak, envelope duration</td>
</tr>
<tr>
<td>Smoorenburg (1982)</td>
<td>Peak, envelope duration</td>
</tr>
<tr>
<td>L(\text{Aeq}) (1983)</td>
<td>Integrated A-weighted energy</td>
</tr>
<tr>
<td>ICE (2016)</td>
<td>Modified AHAH, corrected errors, total energy entering cochlea</td>
</tr>
<tr>
<td>Kurtosis adjusted L(\text{Aeq})</td>
<td>Integrated A-weighted energy, adjustment for temporal envelope variability</td>
</tr>
</tbody>
</table>
### Damage-Risk Criteria

<table>
<thead>
<tr>
<th>Source</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>DRC (1965)</td>
<td>Peak, envelope duration, pressure wave duration</td>
</tr>
<tr>
<td>CHABA (1968)</td>
<td>Peak, envelope duration, Middle ear muscle contractions</td>
</tr>
<tr>
<td>MIL-STD-1474 A/D</td>
<td>CHABA + Hearing protector (20 dB peak reduction)</td>
</tr>
<tr>
<td>Pfander (1975)</td>
<td>Peak, envelope duration</td>
</tr>
<tr>
<td>MIL-STD-1474 A/D</td>
<td>Helix, envelope duration, Middle ear muscle contractions</td>
</tr>
<tr>
<td>L10 (1983)</td>
<td>Integrated A-weighted energy</td>
</tr>
<tr>
<td>AHAHH (1991)</td>
<td>Waveform fine structure, middle ear muscle contractions, stapes limiting,</td>
</tr>
<tr>
<td>ICE (2016)</td>
<td>Modified AHAHH, corrected errors, total energy entering cochlea</td>
</tr>
</tbody>
</table>

### Questions

1. How do the DRC limits differ across a wide range of civilian firearms?

2. How accurately can the outcomes of one DRC be predicted by another?

### Methods - Guns

- **Pistols (conditions = 14)**
  - Caliber: .22 to .45 ACP
  - Barrel length: 3 to 5.5 inches
  - Action: Revolver and semi-automatic

- **Shotguns (conditions = 14)**
  - Caliber/Gauge: .410 to 10 gauge
  - Barrel length: 21 to 27.5 inches
  - Action: Single shot, over/under, pump, semi-automatic

- **Rifles (conditions = 26)**
  - Caliber: .17 to .458 Winchester Magnum
  - Barrel length: 18.5 to 26 inches
  - Action: Bolt, lever, semi-automatic
  - Muzzle brakes on .270, 7mm magnum, .300 Winchester Magnum
Methods - Measurement

- 18 microphones, 1.5 m above ground
  - At shooter’s left ear
  - 3 radial distances (1.5, 3 and 6 m)
  - Grazing incidence

Instrumentation

- National Instruments PXIe-4499
- National Instruments PXI-4462
- 1/8” and 1/4” microphones

Murphy et al., NHI 2012

Methods - Analyses

Data processing and management

- MATLAB

Data set

- 54 gun conditions
- 5 gunshots per firearm
- 18 microphone channels
- 4,860 impulse recordings
- 7 Damage-risk criteria

DRC calculations

- Waveform summaries: MATLAB
- LAeq, LIAeq: MATLAB
- AHAAH: MIL-STD-1474E (AHAAH version 2.1)
- ICE: MATLAB/Simulink

Regression analyses

- Stata v. 15
- Ordinary Least Squares regression

ICE analyses were conducted by B. Zagdou, L3 Applied Technologies, Inc.

A Bird’s Eye View
Regression Predictions

Multiple regression
• DV: Log MPE on new DRC
• IV 1: Log MPE on old DRC
• IV 2: Squared Log MPE on old DRC
• Constant: difference in permissible exposures if the IV considers 1 shot permissible

Transformations from CHABA (1968)

CHABA and LAeq agree at 100 MPE
Minimum R² = .88
If CHABA MPE = 1:
MPE factor is 20 times greater (LIAeq) to 8 times less (ICE no Reflex)
All slopes are shallower than CHABA

Transformations from LAeq or LIAeq

• Minimum R²
  • LAeq: .89
  • LIAeq: .89
Transformations from AHAH

- Minimum $R^2$
  - Unwarned: .86
  - Warned: .87

Transformations from ICE

- Minimum $R^2$
  - No AR: .90
  - Unwarned: .89

Estimation Error and Implications

Proportions of variance explained were above .85

Interquartile (More Likely than Not) range of predicted MPE was ± 2 dB or less
  - Except if predicting CHABA, which has been abandoned

Errors similar to test-retest differences and uncertainty within a single study.
Conclusions

Damage-risk criteria use the same information
- Same construct, different indicators
- Vastly different limits
- High correlations and predictability

At most, one approach is correct
- All have been developed using available data, which are limited
- Informed selection can only occur through careful prospective study

Reasonable transformations across DRCs can be made
- Prior studies using abandoned DRCs are still usable

Questions?

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What about longer A-durations?

- Peak levels:
  - 142 to 174 dB SPL
- A-durations:
  - 0.25 to 4.7 ms

75 mm pack Howitzer, blanks and 10 gauge blanks, 1 m to 24 m distances
What about protected waveforms?

AR15 rifle
Peak levels 130, 150, 170 dB SPL
Four hearing protector conditions

What about protected waveforms?

... (diagram with data points)

Figure 6: Correlation between L_leq and AR15 NRR metrics for (a) in-ear and (b) in-ear equivalent pressure waveforms measured behind the ear (IEP) and (c) in-ear equivalent pressure waveforms with simulated hearing protectors. Each dot represents the metric from a single impulse. Color indicates estimated derived hearing protection distribution (PA, dB).

What about reverberant environments?

.22 caliber revolver
Hunting blind
Dimensions: 1.8 m x 1.8 m x 2 m
16 locations
What about the missing 10% of Variance?

Flamme & Murphy, NHCA 2012

Comparison of the Reduction in Damage Risk Criterion
MilStd 1474D, $L_{Aeq8hr}$, Log$_{10}$(ARU) with Peak Level Reduction

DRC Criteria Reduction (dB) vs. Peak Level Reduction

Slides from Flamme, 2012 AIHCE presentation

- AHAH is less permissive than $L_{Aeq8}$
- Bigger differences for low-level signals
  - 200 vs. 4,000
- Nearly all variance in one DRC can be predicted by the other
• AHAH is more permissive than Coles/CHABA at high levels and less permissive at low levels
  • Bigger differences for low-level signals
  • 90 vs. 9,000,000
• Strong relationship between DRCs

Slide:
Signals = 953; sources = 8; distances 0.5 to 8 m; open field

Slide:
LAeq8 is more permissive than Coles/CHABA at high levels and less permissive at low levels
• Bigger differences for low-level signals
  • 2,000 vs. 9,000,000

Slide:
Signals = 953; sources = 8; distances 0.5 to 8 m; open field